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COAL GASIFICATION SYSTEMS ENGINEERING AND ANALYSIS FINAL REPORT
APPENDIX F: CRITICAL TECHNOLOGY ITEMS/ISSUES

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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1.0 INTRODUCTION

The Tennessee Valley Authority has initiated a project encompassing the construction and operation of a four module 20,000 TPD coal gasification plant at Murphy Hill, Alabama. While final selection of the gasification technology is yet to be made, it will be chosen from Koppers-Totzek (KT), Texaco, Babcock & Wilcox, Lurgi, and BGC/Lurgi with KT and Texaco the favorite candidates. NASA in a cooperative working arrangement with TVA is engaged in a system analysis and study program designed to provide project support for the project. This study has as its objective the defining of critical technology items and issues in which there is a need for development as research in order to assure technical and economic success for the state-of-the-art of coal gasification in the United States.

Coal gasification is a relatively unknown technology to the U. S. on a commercial industry basis. Much of the data available on commercial scale systems is generally controlled by interests from outside the U. S. While small pilot units have demonstrated various process results for a wide variety of cases, such units have not provided commercial reliability or performance data for large scale equipment.

Design data are currently primarily extrapolated from such industries as chemical, oil refining, and steel making. Control and instrumentation systems are either conceptual or based on small units from which design scale-up data are often not the object of the program.

Technology development needs span all of the systems. Table 1.1 presents the technology development needs for the main processing units. Table 1.2 is a similar presentation for supporting units. While development needs are shown for a large number of systems, the most critical areas are associated with the gasifier itself and those systems which either feed the gasifier or directly receive products from the gasifier. Tables 1.2 through 1.6 define those areas of technology development needs.

TABLE 1.1

TECHNOLOGY DEVELOPMENT NEEDS

MAIN PROCESS UNITS

	COAL FEEDING	GASIFICATION	GAS COOLING	GAS PURIFICATION	SHIFT CONVERSION*	METHANATION
PROCESS DESIGN						
DATA	X	X	X	X	X	
METHODS		X	X			
MECHANICAL DESIGN						
SCALE	X					
MATERIALS OF CONSTRUCTION	X	X	X		X	
EQUIPMENT RELIABILITY	X	X	X	X	X	X
PROCESS CONTROL						
DEVICES						
SENSING	X	X	X		X	X
CONTROL		X				
METHODS		X	X		X	X
OPERATIONS						
LONG (8000-HR) COMMERCIAL SCALE RUNS		X	X	X	X	X
BY-PRODUCT RECYCLE		X	X			

*DEVELOPMENT NEEDS LESS SEVERE THAN THOSE OF OTHER SYSTEMS

TABLE 1.2
TECHNOLOGY DEVELOPMENT NEEDS

	SUPPORTING UNITS					
	COMPRESSION	OXYGEN PLANTS	TAR/OIL SEPARATION	SULFUR RECOVERY	WASTEWATER TREATMENT	SOLIDS DISPOSAL
PROCESS DESIGN						
DATA			X	X	X	X
METHODS			X			
MECHANICAL DESIGN						
SCALE	X	X				
MATERIALS OF CONSTRUCTION	X		X			
EQUIPMENT RELIABILITY	X		X			X
PROCESS CONTROL						
DEVICES						
SENSING					X	X
CONTROL					X	
METHODS						
OPERATIONS						
LONG (8000-HR) COMMERCIAL SCALE RUNS						X
BY-PRODUCT RECYCLE			X			

TABLE 1.3

MATERIALS OF CONSTRUCTION

- CONVENTIONAL MATERIALS FOR PETROLEUM REFINING AND PETROCHEMICAL PLANTS MAY BE INADEQUATE IN COAL GASIFICATION PLANTS.
  - -- EROSION AND CORROSION MECHANISMS MAY BOTH BE IMPORTANT
  - -- MANY DIFFERENT CONSTITUENTS MAY BE PRESENT AT ONE TIME
- IN PARTICULAR, MANY ALLOYS EXHIBIT A TRANSITION TO RAPID CORROSION AFTER 1000 TO 5000 HOURS, AT HIGH H_2S CONCENTRATIONS CHARACTERISTIC OF COAL GASIFICATION ATMOSPHERES.
- AREAS OF HIGH-H_2O PARTIAL PRESSURE MAY SUBJECT CERTAIN REFRACTORIES TO DEGRADATION BY LEACHING OF SILICA FROM THE MATERIAL.
- MULTIPLE-LAYER MATERIALS MAY OFFER BETTER PROTECTION AGAINST COAL GASIFIER ENVIRONMENTS THAN ANY SINGLE SUBSTANCE.

TABLE 1.4
PROCESS CONTROL REQUIREMENTS

- DEPENDS ON
  - END USE
  - MULTIPLICITY OF TRAINS
  - TYPE OF GASIFIER
- RAPID SENSING OF FAILURES OR CHANGES IN PROCESS CONDITIONS
- POSITIVE CONTROL MEASURES
  - TURNDOWN/LOAD FOLLOWING
- DUPLICATION AND REDUNDANCY ARE ESSENTIAL
- COMPUTER GUIDED CONTROL MAY BE REQUIRED, ESPECIALLY FOR COMPLEX, CLOSELY COUPLED SYSTEMS

TABLE 1.5

SENSING AND MEASUREMENT REQUIREMENTS

- PRESSURES TO 1200 PSIG
- TEMPERATURES TO 3000°F
- FLOW OF GAS, LIQUIDS, AND SOLIDS
  - GASES CONTAINING H_2, H_2S, TARS, OILS, PARTICULATES CHLORIDES, ALKALIS AT TEMPERATURES TO 3000°F, PRESSURES TO 1200 PSIG
  - SOLIDS
    - COAL FEED TO GASIFIER
    - ASH OR SLAG FROM GASIFIER
    - TAR/OIL/FINES RECYCLE RATES
- PARTICULATE RATE AND SIZE CONSISTS
  - HOT DIRTY GAS
  - ADSORBED TARS AND OILS
- ON-LINE ANALYSIS
  - PRIMARY COMPOUNDS: H_2, CO, CO_2, H_2O, CH_4, N_2
  - POLLUTANTS: H_2S, COS, HCN, NH_3
  - CONDENSIBLES: PHENOLS, AROMATICS, OLEFINS, TARS, ACIDS
  - SOLID WASTES: METALS, ALKALI SALTS
- INVENTORY
  - BED LEVEL IN FIXED-BED AND FLUID-BED GASIFIERS
- SAFETY
  - IN-GASIFIER MONITORING OF OXYGEN BREAKTHROUGH
  - INTEGRITY OF REFRACTORY LININGS

TABLE 1.6

MEASUREMENT AND CONTROL REQUIREMENTS

- **SENSING AND MEASUREMENT**
  - -- PRESSURE IN GASIFIER RAW GAS STREAMS
  - -- TEMPERATURE INSIDE GASIFIERS
  - -- FLOW OF GASIFIER RAW GAS, FEED COAL, AND ASH
  - -- PARTICULATE CONTENT OF GASIFIER RAW GAS
  - -- ANALYSIS OF CONSTITUENTS OF GASIFIER RAW GAS
  - -- INVENTORY OF COAL WITHIN THE GASIFIER
  - -- GASIFIER SAFETY MONITORING

- **CONTROL VALVES**
  - -- PRESSURE LETDOWN ON SOLIDS AND SLURRY STREAMS
  - -- FLOW AND PRESSURE CONTROL ON HOT DIRTY GAS STREAMS
  - -- SHUTOFF VALVES FOR MULTI-TRAIN INSTALLATIONS

TABLE 1.7

TECHNICAL ISSUES IN DOWNSTREAM PROCESSING

- **END-USES MAY DICTATE PRODUCT PURITY SPECIFICATIONS AND, THEREFORE, UPGRADING REQUIREMENTS**
  - -- COMBINED-CYCLE POWER PLANTS OR INDUSTRIAL BOILERS MAY HAVE LOAD-FOLLOWING REQUIREMENTS WHICH IMPOSE:
    - -- TURNDOWN REQUIREMENTS
    - -- PROCESS CONTROL REQUIREMENTS
  - -- FEDERAL, STATE, AND LOCAL REGULATIONS MAY DICTATE EFFLUENT TREATMENT REQUIREMENTS WHICH REQUIRE:
    - -- KNOWLEDGE OF DETAILED COAL COMPOSITION
    - -- KNOWLEDGE OF DISTRIBUTION OF COAL CONSTITUENTS WITHIN THE SYSTEM
- **PROCESS DESIGN ISSUES FOR NON-GASIFICATION UNITS**
  - -- IS THE PROCESS COMMERCIALIZED ON SAME OR SIMILAR FEEDS?
  - -- ARE DESIGN METHODS AVAILABLE?
  - -- ARE DESIGN DATA AVAILABLE?
- **MECHANICAL DESIGN ISSUES**
  - -- MATERIALS OF CONSTRUCTION
  - -- TEST PROGRAMS
  - -- PRIOR EXPERIENCE IN SIMILAR SERVICE

Downstream processing units are closer in nature to commercial operations of the same or similar processes. However, the scale of coal gasification plants and the uncertainty associated with unfamiliar components which may be present in coal gasification process streams result in certain technical issues. Table 1.7 outlines these issues.

2.0 IDENTIFICATION OF CRITICAL TECHNOLOGY ITEMS AND ISSUES

Critical technology items/issues were identified by a three-component approach. First, a select BDM/Mittelhauser team of technologists and design engineers were assembled for a "walk through" of each of the systems defined in the Coal Gasification Catalog, Appendix A. Subsystems and components were identified as to their development needs based on the team's previous experience. Second, a review of published gasification design efforts and other literature sources was conducted. Critical items/issues identified in the reports were extracted. Third, team members have had personal communication with Honeywell concerning instrumentation and control technology, North American Rockwell concerning equipment performance especially valves, and the Electric Power Research Institute concerning their views of technology development needs. Finally, a team member attended the Symposium on Instrumentation and Control for Fossil Energy Processes conducted by the U. S. Department of Energy at Virginia Beach, Virginia, in June, 1980.

The critical items/issues identified are listed in Section 6.0 and identified according to their area of impact. Areas of impact are defined in Table 2.1.

3.0 PRIORITIZATION OF CRITICAL ITEMS/ISSUES

The state-of-the-art relative to the design and operation of coal gasification plants is such that sufficient alternatives exist in all areas to make coal gasification projects technically feasible. However, in some areas, considerable margin in design philosophy is required for lack of good data.

Likewise, operation of coal gasification plants are projected to incur problems in service factors and plant efficiency due to less than desirable equipment performance and control techniques.

Technology development programs, especially equipment development programs, are generally very costly and have their justification based on application of results on an industry-wide basis. Therefore, in order that a concentrated effort might be directed toward items/issues of particular interest to the TVA project and thus have a relatively early pay back, the items/issues listed in Section 6.0 have been prioritized. For purposes of prioritization, it has been assumed that:

- minimum O&M savings should equal at least 0.13 times the cost of development and associated capital cost increases leading to those savings
- increased reliability resulting from improved technology may be evaluated based on service factor considerations
- improvements in efficiency resulting from improved technology take the form of increased product from a fixed energy input.

Figure 3.1, based on the sensitivity analysis in Chapter V, illustrates the potential for price reduction due to increased service factor. At the 90 percent level, a one percent increase in service factor yields approximately a 0.4 percent cost reduction. For the 20,000 TPD TVA K-T MBG facility, this corresponds to $2.3 MM/year savings in January 1980 dollars for a one percent increase in service factor. Using the 0.13 factor, this implies that approximately $18 MM are justified in development costs to yield a one percent service factor increase.

An increase of one percent in efficiency would provide an additional 4,400 MMBtu's per day and pay for up to $73 MM in development and capital costs required to attain the increase.

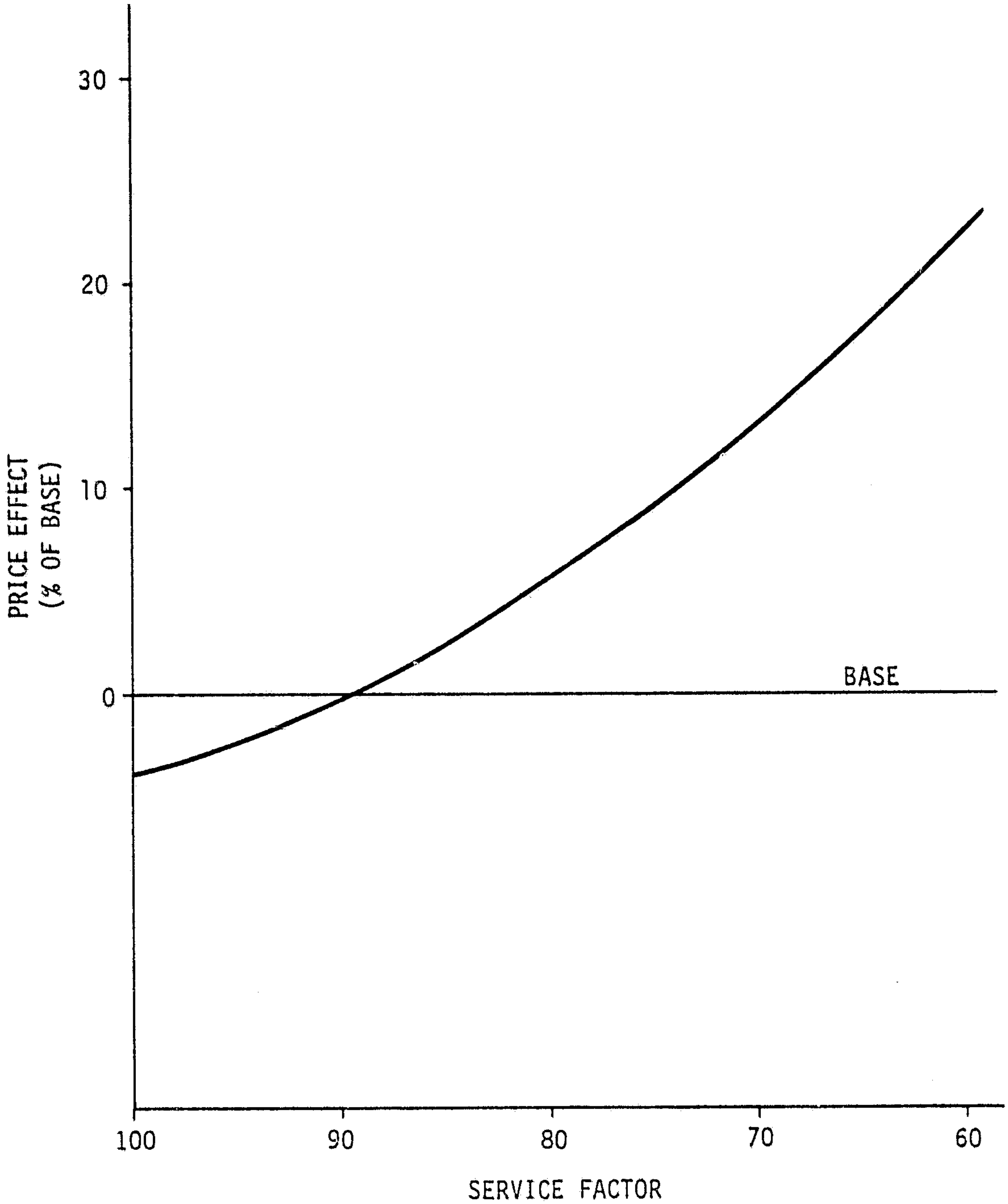

FIGURE 3.1 SERVICE FACTOR EFFECTS

These illustrations are intended only to show the order of magnitude of developmental effort which is justified based on supporting a single large plant project. A more precise analysis would need to consider other factors such as tax treatment of R&D expenditures, probability of success, and potential for application.

Analyses conducted in this project have assumed a stream factor of 90 percent. In practice, 80-85 percent may be more typical. Thus, the potential for improvement may be substantial. A study of the experience outside the U. S. should provide insight into this potential. Likewise, the potential for stream factor improvement based on single component effects requires analysis of experience and is complicated by the potential for on-line sparing. A review of experience to date is required to provide a basis for estimating the potential pay-off from any given component life improvement.

Based on an analysis of the list of critical items, the greatest potential for significant improvement in service factor or efficiency involves those items associated directly with the gasifier reactor and those items such as waste heat boiler and exchangers associated with the recovery of the exothermic heat produced by the reactor.

The list of high priority items thus includes gasifier refractory, reactant feed control, coal feed equipment, waste heat boiler development, and material of construction associated with these items.

Other items have less potential for large impact on the coal gasification plant, but represent less development costs.

4.0 RECOMMENDED DEVELOPMENT ITEMS/ISSUES

Each of the identified critical items/issues has the potential for solution and probable justification for a developmental effort when considering across the board needs of an impending coal gasification industry. However certain items/issues have been selected for recommendation here based on their potential for large impacts and applicability to the TVA project.

4.1 Refractory

The internals of the coal gasification reactors considered in this study have refractory linings to protect the containment vessel from hot reactants and ash. The K-T, Texaco, B&W, and BGC/Lurgi each operate above the fusion point of the ash and thus their internals are exposed to molten slag. Refractory failure due to such mechanisms as erosion and silica leaching is a problem which potentially will contribute to poor service factors or efficiency reduction and capital cost solutions.

One approach to avoiding the problem is to operate the process such that a layer of solidified slag protects the reactor refractory from exposure to molten slag. This procedure requires that a substantial heat flux through the slag layer be absorbed by raising steam. In low pressure operations such as those of the K-T reactor this results in excess low pressure (25 psig) steam of marginal value. The ability to limit low pressure steam production to that required as process reactants would improve the plant thermal efficiency. The B&W gasifier design utilizes the production of high pressure steam in boiler tubes imbedded in the reactor refractory as a means of operating at higher efficiency. This design is believed to add substantially to the capital cost of the gasifiers.

The Texaco coal gasification design does not provide for substantial heat transfer through the refractory and thus is dependent upon refractory integrity for a high operating service factor. Long refractory life (8,000 hours or more) is not known to have yet been demonstrated though some progress apparently was made in the recent pilot plant operations in Germany.

The BGC/Lurgi gasifier decreases the severity of the problem by adding a fluxing agent to form a lower melting temperature slag. This approach is an aid but not a solution to the refractory integrity problem and results in the cost and logistic problems associated with the flux system.

Providing for frequent refractory replacement through sparing of equipment requires sparing of the entire reactor, feed system, and heat recovery train and represents substantial capital investment in addition to the added maintenance costs.

Based on these discussions, refractory development is recommended as a developmental item.

4.2 Waste Heat Recovery

Gases leaving an entrained bed coal gasifier are at a temperature ranging from 2500 to 3300°F. Recovery of the sensible heat associated with these temperatures is of prime importance in process thermal efficiency. These hot gases contain entrained molten slag, CO, CO_2, H_2, H_2O and varying quantities of sulfur and nitrogen bearing gases, and lessor quantities of such things as vaporized metals, chlorine, etc. Recovery of useful heat from this stream requires quenching to solidify the entrained ash, perhaps recovery of the bulk of this ash, and the raising of steam in a high pressure waste heat boiler (WHB) followed by final ash scrubbing and cooling. The K-T and B&W designs both have a WHB section close coupled to the reactor. The B&W design is untested. The service factor associated with the K-T design is not known but cleaning and maintenance requirements are believed to be high though plant service factors in the mid-80 percent range have been reported. The Texaco reactor conceptually operates with extensive quenching to avoid the high severity heat recovery or with a WHB as yet unproven on coal operations.

Technology problems arise from the selection of materials of construction to handle the severe conditions, the erosive effects of fine ash particles, and deposition of and subsequent fouling by entrained ash.

Development of improved waste heat recovery equipment has the potential for major efficiency effects. A program to develop new technology and evaluate improvements by other equipment developers is recommended.

4.3 Reactor Instrumentation

Temperatures inside of an entrained coal gasifier are in the range of 2500°F to 3300°F. Measurement of this temperature is not now possible on a continuous basis. Control of this temperature is important from the standpoint of plant efficiency, slag viscosity control and where applicable solid slag layer thickness control. Control can now be accomplished by monitoring the coal composition, reactor product composition - particularly CO_2 content, and controlling O_2 and steam reactants accordingly. The controlled temperature is actually a calculated value and subject errors and variations in the coal feed composition and quantity. Direct temperature measurement would allow more precise control of the O_2 and steam reactants. Since an excess molecule of O_2 results in two molecules CO be converted to CO_2 (or H_2O as dictated by the water gas shift reaction), precise control of reactant proportions can have a significant effect on thermal efficiency. Data from which to estimate the magnitude of this problem in operating plants is not available for this study. However, the value of increased efficiency is sufficient, particularly when coupled with potential safety benefits, to warrant a recommendation for a development effort in this area. Similarly a technique for detecting hot spots resulting from defective refractory would be helpful particularly for systems where the detection is made difficult by the overriding effect of steam jackets or tubes and insulation. For molten slag property control, there is no downstream measurement to use as a basis for feed back control.

4.4 Solid Feed Control

Precise solid feed measurement and control is an area which relates to plant efficiency by its effect on the control of the proper ratio of gasifier reactants. Given the very short residence time in an entrained gasifier, near instant response is required for precise control in plant performance. Development efforts in this area are also attractive for their potential at retrofitting in the TVA plant and justify a developmental effort.

4.5 Dynamic Analysis

The operation of MBG plants and in particular the TVA plant will be subject to usual process plant variations such as those resulting from equipment failure or external influences and in addition a probable variable load demand which must be followed. It is recommended that a computerized dynamic model be developed so as to aid the development of total plant control strategy and possible application in future personnel training programs

4.6 Other

There are a number of other items/issues which merit consideration for which no particular recommendation is made here. Examples of these are listed in Table 4.1. A particular comment related to mechanical items which are easily spared, such as pumps and control valves, is offered. Generally an extensive development effort is justified by application of results to an industry rather than a single installation. Such developmental work is best suited for equipment manufacturers. Should NASA elect to utilize their mechanical design and materials expertise in these areas it is recommended that such efforts be coordinated and combined with commercial manufacturers of such equipment and maximum use of existing test facilities such as the DOE/METC hot gas loop test facility.

5.0 RESOURCE REQUIREMENTS

The technology development programs discussed above for possible implementation by NASA are selected such as to minimize the different types of test facilities required. Generally, the programs can be grouped into those that require a molten ash test facility, a large hot dirty gas prototype equipment, test rig, utilization of existing test units other than NASA's, and no hardware requirement.

TABLE 4.1. CRITICAL TECHNOLOGY ITEMS/ISSUES

SUBSYSTEM	CRITICAL ITEM	TECHNICAL STATUS	KEY ISSUE	ACTION	TIME REQ. (MONTHS)	COST, $ x 10^6
COAL PREPARATION	DRYING	CURRENTLY USES HEAT FROM COMBUSTION OF COAL	ENERGY CONS. & ECON.	BETTER DRYING TECHNIQUES (MICROWAVES)	6 24	LAB SCALE - 0.2 PILOT SCALE - 5.0
GASIFICATION	AGGLOMERATION WITH CAKING COAL (LURGI)	TESTING IN PROGRESS	OPERABILITY	TECH ASSESSMENT	6	0.2
	CONTINUOUS DRY COAL FEEDING	UNDER DEVELOPMENT	OPERABILITY & ECON.	TECH ASSESSMENT DEVELOPMENT PROGRAM	4 36	0.1 4.0
	PILOT PLANT TESTING ON PLANT COAL	NOT YET DONE	OPERABILITY & SCHEDULE	TEST PLANT COAL	10	3.0
	GASIFICATION CATALYSIS	SOME DEVELOPMENTAL WORK	ECONOMIC	TECH ASSESSMENT DEVELOPMENTAL PROGRAM	4 40	0.15 8.0
	MATERIALS RELIABILITY	SOME DEVELOPMENTAL WORK	OPERABILITY	TECH ASSESSMENT PILOT PLANT PROGRAM	6 20	0.2 4.0
GAS QUENCH, WASTE HEAT RECOVERY, AND COOLING	DISTRIBUTION OF GASEOUS AND TRACE METAL COMPS.	LITTLE DEVELOPWORK	SCHEDULE & OPERABILITY	METHODS EVALUATION PILOT SCALE TESTING USING NASA ROCKET TEST STANDS	6 36	0.3 5.0
	MATERIALS RELIABILITY	SOME DEVELOPMENTAL WORK	OPERABILITY	TECH ASSESSMENT PILOT PLANT PROGRAM MODULE #1 TEST PROGRAM	6 20 72	0.2 4.0 3.0
ACID GAS REMOVAL	COS REMOVAL	SOME TEST WORK	OPERABILITY & SCHEDULE	TECH ASSESSMENT HYDROLYSIS TEST PROGRAM	6 12	0.2 4.0
	SOLVENT DEGRADATION	LITTLE TEST WORK	OPERABILITY & ECON.	LABORATORY TESTING MODULE #1 TEST PROGRAM	12 60	0.4 2.0
	DISTRIBUTION OF ORGANICS	LITTLE TEST WORK	OPERABILITY	LABORATORY TESTING MODULE #1 TEST PROGRAM	12 60	0.4 2.0
ALTERNATE PRODUCTS	CATALYST POISONING	SOME TESTING	OPERABILITY & ECON.	LABORATORY TESTS MODULE #1 TESTS	12 36	1.5 6.0
	PRODUCT UTILIZATION (METHANOL IN GASOLINE)	SOME TESTING	ECONOMICS	TECH ASSESSMENT PILOT TESTS	6 24	0.2 3.0
SULFUR RECOVERY	LEVEL OF MINOR COMPONENTS HCN, COS, CS_2, RSH, H_xC_x	OPERATING PLANTS WITHOUT COMPONENTS	OPERABILITY & SCHEDULE	DEFINE QUANTITY MODULE #1 TESTING	6 12	1.0 6.0
	MATERIALS RELIABILITY IN SO_2 REMOVAL	SEVERAL TEST PROGRAMS	OPERABILITY	TECH ASSESSMENT MATERIALS TESTING	6 24	0.2 4.0
WATER TREATING	NITROGEN REMOVAL	SOME TESTING	SCHEDULE & OPERABILITY	LABORATORY TESTS MODULE #1	12 12	0.5 2.0
	TRACE ORGANIC REMOVAL	LITTLE TESTING	SCHEDULE & OPERABILITY	LABORATORY TESTS MODULE #1 TESTING	12 12	0.5 1.0
	BUILDUP OF MINOR COMPONENTS (CHLORIDE)	LITTLE TESTING	OPERABILITY	WATER SYSTEM MODELING MODULE #1 TESTING	9 24	0.6 1.0
	TRACE METALS IN WASTES	SOME TESTING	SCHEDULE	TECH ASSESSMENT PILOT PLANT TESTS MODULE #1 TESTS	6 12 36	0.3 2.0 3.0
SOLID WASTE DISPOSAL	LEACHABILITY OF METALS	SOME TESTING	SCHEDULE	LABORATORY LEACHING TESTS MODULE #1 TESTS	9 18	0.6 1.5

5.1 Molten Ash Facility

Developmental work in areas such as refractory improvement, high temperature measurement in a molten slag environment, and molten slag viscosity modification and measurement require a bench scale size molten ash research vessel and supporting equipment. This facility should be capable of generating temperatures in the 2500-3300°F range. In addition to temperature control, the ability to vary the oxidation/reduction characteristics of the test environment as well as the steam partial pressure would be helpful. The facility should include provision for testing developmental results in temperature measurement.

5.2 Gas Equipment Prototype Test Unit

The development of waste heat recovery and initial gas cleanup requires that large prototype equipment be tested. Because of the importance of gas velocities and flow patterns on the erosive and ash disposition characteristics of the system, scale-up of test results will be limited. Therefore, the test facility should be capable of producing an amount of gas equivalent to several hundred tons of coal per day under varying pressure conditions. The minimum size of the facility would be determined by a thorough dynamic similarity analysis. Likewise, determining the long term effects of the hot raw gas on the prototype materials of construction will require that the facility be built anticipating test runs of several thousand hours.

The best situation for conducting large tests of this nature is with a slip stream or dedicated reactor operated in conjunction with an operating commercial facility such as the TVA plant. This approach eliminates concerns and costs associated with feed preparation, product disposition, and utility supply. However, if this approach is not feasible, the recommended alternative is a test facility based on oil gasification with impurity spiking to simulate coal gasification products. This approach could be made near equivalent to a coal gasification based test facility and would be free of the complications of a coal supply and feed system. Figure 5.1 shows this concept.

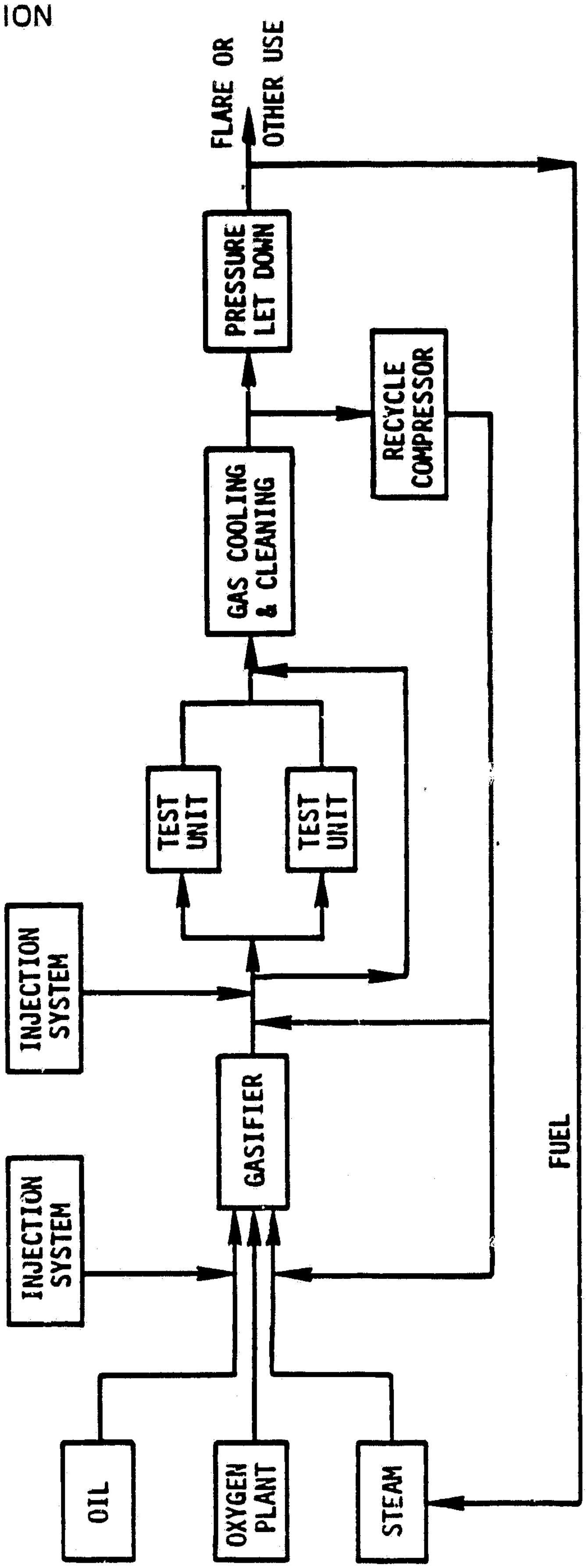

Figure 5.1. Conceptual Test Facility

Oil is gasified in a partial oxidation facility with oxygen from an air separation plant and steam to produce a synthesis gas which may be "spiked" as desired either before or after gasification to produce a test gas. Provision for parallel test loops in which skid-mounted prototype waste heat recovery and gas cleanup equipment may be inserted are recommended for maximum flexibility. Following the test loops, provision must be provided for gas cooling and cleaning of the effluent from either the test loops or the gasifier as required. Water quenching and acid gas removal are required though the latter is only needed for the net gas leaving the system. The cool clean gas may be either recycled or let down in pressure for disposition as fuel or other use. Recycling of the product gas will substantially reduce the oil requirement and the product disposition problem. The possibility of using the recycle gas as a heat sink to control reactor temperature instead of steam should be investigated as well as recycling downstream of the reactor to control temperatures to the test loops. Since oil gasification is a commercially available process from either Shell or Texaco, it is recommended that one of these companies be contracted to supply the design for the gasifier unit.

Depending upon the actual size unit selected, a facility such as this may be expected to cost 20 to 50 million dollars.

5.3 Staffing

Staffing requirements for a major effort in coal gasification technology development will vary according to the number of the items/issues addressed. However, if a large hot gas processing test loop is included, this unit will dominate the number of personnel requirement.

A significant effort for the molten ash facility would require a minimum of two professionals with expertise in ceramics and temperature measurement supported by three or four laboratory technicians.

The large hot gas processing test loop operating continuously will require a staff of 40 to 50 personnel consisting of about 20 operators, 4 shift supervisors, 4 shift engineers, 6 shift maintenance personnel, 4 regular maintenance personnel, and a project technical and support staff.

6.0 CRITICAL TECHNOLOGY ITEMS/ISSUES

The following compilation contains the results of the identification of critical items/issues.

TABLE 6.1. CRITICAL TECHNOLOGY ISSUES

SYSTEM/NUMBER Coal Preparation and Feeding

SUBSYSTEM	COMPONENT/ DESIGN DATA	ISSUE	DESIGN	COST REDUCTION			OPERABILITY				
				INITIAL CAPITAL	REPLACEMENT CAPITAL	ANNUAL MAINTENANCE	PRODUCT SPECS	EMISSION SPECS	ON-STREAM TIME	EFFICIENCY	SAFETY
Feeding	Lock Hopper Pressurized Feed	High pressure operation, lower compression costs.	✓	✓						✓	
Slurry Water	Quench Recycle Water	Trace metal and Polyaromatic Hydrocarbon content.	✓					✓			✓
Slurry	Viscosity/ Solids Data	Slurry system design.	✓							✓	
Heated Slurry	Heat Transfer and Viscosity/ Temperature Data	Design Slurry Preheater.	✓							✓	
Blending	Ash Fusion Properties of Blends	Design gasifier, waste heat boiler and blending system, operate blending system.	✓				✓	✓			✓
Blending (Lurgi)	Caking Properties of Blends	Design blending system.	✓				✓	✓	✓		
Feed (Lurgi)	Fines Agglomeration and Feeding	Design fines utilization method.	✓							✓	

TABLE 6.1. CRITICAL TECHNOLOGY ISSUES (continued)

SYSTEM/NUMBER Coal Preparation and Feeding (1)

SUBSYSTEM	COMPONENT/ DESIGN DATA	ISSUE	DESIGN	COST REDUCTION			OPERABILITY				
				INITIAL CAPITAL	REPLACEMENT CAPITAL	ANNUAL MAINTENANCE	PRODUCT SPECS	EMISSION SPECS	ON-STREAM TIME	EFFICIENCY	SAFETY
Size Reduction	Wet Grinding	Size distribution to maximize slurry solids concentration.	✓							✓	
Size Reduction	Pulverization	Maximize gasifier carbon conversion.	✓							✓	
Size Reduction	Design Coal Data	Design of grinding and pulverizing	✓							✓	
Drying	Design Coal Data	Design drying subsystem.	✓							✓	
Drying	New Technology	Lower energy requirements.	✓							✓	
Feeding	Slurry Pumps	Severe erosion and surface fatigue.			✓	✓			✓		✓
Feeding	Mass Flow Rate Measurement	Gasifier Control					✓	✓			✓

TABLE 6.1. CRITICAL TECHNOLOGY ISSUES (continued)

SYSTEM/NUMBER Acid Gas Removal (4)

SUBSYSTEM	COMPONENT/ DESIGN DATA	ISSUE	DESIGN	COST REDUCTION			OPERABILITY				
				INITIAL CAPITAL	REPLACEMENT CAPITAL	ANNUAL MAINTENANCE	PRODUCT SPECS	EMISSION SPECS	ON-STREAM TIME	EFFICIENCY	SAFETY
Contactor	Solvent	COS & HCN degradation.			✓	✓	✓	✓	✓		
Contactor	Membranes, Absorbers, Ads.	Removal efficiency.			✓	✓			✓	✓	
Contactor	Catalyst	Removal efficiency, lifetime.		✓	✓	✓			✓		
Contactor	COS Removal	Meet specs and protect downstream equipment			✓		✓	✓			✓
Regenerator	CO_2 Vent	Recycle to gasifier.		✓						✓	

TABLE 6.1. CRITICAL TECHNOLOGY ISSUES (continued)

SYSTEM/NUMBER Coal Gasification (2)

SUBSYSTEM	COMPONENT/ DESIGN DATA	ISSUE	DESIGN	COST REDUCTION			OPERABILITY				
				INITIAL CAPITAL	REPLACEMENT CAPITAL	ANNUAL MAINTENANCE	PRODUCT SPECS	EMISSION SPECS	ON-STREAM TIME	EFFICIENCY	SAFETY
Gasifier	Feed Nozzle	Erosion			✓	✓			✓		✓
Gasifier	Minor Constituent Yields	Downstream system designs.	✓	✓							
Gasifier	Sensing instruments and control systems	Rapid response, refractory protection	✓				✓	✓			✓
Gasifier	Metal parts	Corrosion due to ash alkali			✓	✓			✓		
Gasifier	Pressure Letdown Valve	Erosion and corrosion			✓	✓			✓		
Gasifier	Physical and Chemical Reactant Behavior	Design scaleup, prediction of yield composition.	✓								
Gasifier (Texaco)	Refractory	Short lifetime			✓	✓			✓		

TABLE 6.1. CRITICAL TECHNOLOGY ISSUES (continued)

SYSTEM/NUMBER Coal Gasification (2)

SUBSYSTEM	COMPONENT/ DESIGN DATA	ISSUE	DESIGN	COST REDUCTION			OPERABILITY				
				INITIAL CAPITAL	REPLACEMENT CAPITAL	ANNUAL MAINTENANCE	PRODUCT SPECS	EMISSION SPECS	ON-STREAM TIME	EFFICIENCY	SAFETY
Slagging	Temperature, Viscosity, Frit Level Measurements	Input signals for slag flow and viscosity control.	✓						✓		✓
Slagging	Lock Hopper Valves	Erosion and corrosion.			✓	✓			✓		
Slagging	Materials	Lifetime			✓	✓			✓		

TABLE 6.1. CRITICAL TECHNOLOGY ISSUES (continued)

SYSTEM/NUMBER Steam Generation/Distribution (15)

SUBSYSTEM	COMPONENT/ DESIGN DATA	ISSUE	DESIGN	COST REDUCTION			OPERABILITY				
				INITIAL CAPITAL	REPLACEMENT CAPITAL	ANNUAL MAINTENANCE	PRODUCT SPECS	EMISSION SPECS	ON-STREAM TIME	EFFICIENCY	SAFETY
Combustor	Tar/Oil/Phenol Combustion Properties	Design combustor.	✓							✓	

TABLE 6.1. CRITICAL TECHNOLOGY ISSUES (continued)

SYSTEM/NUMBER Waste Water Treatment (18)

SUBSYSTEM	COMPONENT/ DESIGN DATA	ISSUE	DESIGN	COST REDUCTION			OPERABILITY				
				INITIAL CAPITAL	REPLACEMENT CAPITAL	ANNUAL MAINTENANCE	PRODUCT SPECS	EMISSION SPECS	ON-STREAM TIME	EFFICIENCY	SAFETY
Oil-Water Separation	Tar and Oil Properties	Design Oil-Water Separator	✓					✓			
Sour water Stripper	Yield Distribution	Downstream water treatment design.	✓					✓			

TABLE 6.1. CRITICAL TECHNOLOGY ISSUES (continued)

SYSTEM/NUMBER Solid Waste Recycling/Disposal (12)

SUBSYSTEM	COMPONENT/ DESIGN DATA	ISSUE	DESIGN	COST REDUCTION			OPERABILITY				
				INITIAL CAPITAL	REPLACEMENT CAPITAL	ANNUAL MAINTENANCE	PRODUCT SPECS	EMISSION SPECS	ON-STREAM TIME	EFFICIENCY	SAFETY
Impoundment Pit	Leachate Electrolyte, Organics, and Trace Metals Content	Design impoundment.	✓					✓			✓
Waste Solids (Mainly Ash)	Leachability, Dustiness	Impoundment facility design.	✓					✓			✓

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TABLE 6.1. CRITICAL TECHNOLOGY ISSUES (continued)

SYSTEM/NUMBER Initial Gas Cleanup and Cooling (3)

SUBSYSTEM	COMPONENT/ DESIGN DATA	ISSUE	DESIGN	COST REDUCTION			OPERABILITY				
				INITIAL CAPITAL	REPLACEMENT CAPITAL	ANNUAL MAINTENANCE	PRODUCT SPECS	EMISSION SPECS	ON-STREAM TIME	EFFICIENCY	SAFETY
Quench	Yields and Phase Distribution	Aqueous, Liquid Hydrocarbon and vapor phase distribution.	✓	✓				✓			✓
Waste Heat Boiler	Materials, Heat Transfer Data, and Performance Data	Withstand hot raw gas, ash corrosion; data to support system design.	✓			✓			✓	✓	

TABLE 6.1. CRITICAL TECHNOLOGY ISSUES (continued)

SYSTEM/NUMBER Instrumentation and Control - Nonsystem Specific (10)

SUBSYSTEM	COMPONENT/ DESIGN DATA	ISSUE	DESIGN	COST REDUCTION			OPERABILITY				
				INITIAL CAPITAL	REPLACEMENT CAPITAL	ANNUAL MAINTENANCE	PRODUCT SPECS	EMISSION SPECS	ON-STREAM TIME	EFFICIENCY	SAFETY
Valves	Flow Control, Pressure Letdown, Block Valves	Jamming, leakage.			✓	✓			✓		✓
Seals	Packing	Particle infusion.				✓			✓		✓
Pumps	Surfaces	Erosion, surface fatigue.			✓	✓			✓		✓

TABLE 6.1. CRITICAL TECHNOLOGY ISSUES (continued)

SYSTEM/NUMBER Flue Gas Desulfurization

SUBSYSTEM	COMPONENT/ DESIGN DATA	ISSUE	DESIGN	COST REDUCTION			OPERABILITY				
				INITIAL CAPITAL	REPLACEMENT CAPITAL	ANNUAL MAINTENANCE	PRODUCT SPECS	EMISSION SPECS	ON-STREAM TIME	EFFICIENCY	SAFETY
Absorbers, Heaters, Mist Eliminators	Construction Materials	Short lifetime.			✓	✓					
Flue Gas Desulfurization	System Chemistry Control	Scale formation.			✓	✓					
Sludge Treatment and Disposal	Stabilization	Dewatering and impoundment.		✓		✓		✓			
Reheater	Heat Transfer Data	Overdesigned for safety.	✓	✓							

TABLE 6.1. CRITICAL TECHNOLOGY ISSUES (continued)

SYSTEM/NUMBER Waste Water Treatment (1B)

SUBSYSTEM	COMPONENT/ DESIGN DATA	ISSUE	DESIGN	COST REDUCTION			OPERABILITY				
				INITIAL CAPITAL	REPLACEMENT CAPITAL	ANNUAL MAINTENANCE	PRODUCT SPECS	EMISSION SPECS	ON-STREAM TIME	EFFICIENCY	SAFETY
Oil-Water Separation	Tar and Oil Properties	Design of oil-water separator.	✓					✓			
Sour Water Stripper	Yield Distribution	Downstream water treatment design.	✓					✓			

TABLE 6.1. CRITICAL TECHNOLOGY ISSUES (continued)

SYSTEM/NUMBER Sulfur Recovery and Tail Gas Treatment (5)

SUBSYSTEM	COMPONENT/ DESIGN DATA	ISSUE	DESIGN	COST REDUCTION			OPERABILITY				
				INITIAL CAPITAL	REPLACEMENT CAPITAL	ANNUAL MAINTENANCE	PRODUCT SPECS	EMISSION SPECS	ON-STREAM TIME	EFFICIENCY	SAFETY
Sulfur Recovery	Sulfur Product and Tail Gas Composition	Sulfur quality, tailgas unit design.	✓					✓			
Tail Gas Unit	Trace Component Conversion	Tail Gas unit design.	✓					✓			

TABLE 6.1. CRITICAL TECHNOLOGY ISSUES (continued)

SYSTEM/NUMBER Air Separation (6)

SUBSYSTEM	COMPONENT/ DESIGN DATA	ISSUE	DESIGN	COST REDUCTION			OPERABILITY				
				INITIAL CAPITAL	REPLACEMENT CAPITAL	ANNUAL MAINTENANCE	PRODUCT SPECS	EMISSION SPECS	ON-STREAM TIME	EFFICIENCY	SAFETY
Compression	Compressor	Improved efficiency.								✓	

7.0 LITERATURE EXAMINED

Table 7.1 presents the reports surveyed as a part of this task. This list is not intended to represent a complete literature survey and contains primarily recent publications. It is intended to show the range of developmental activities taking place in the area of coal gasification.

TABLE 7.1. RECENT PUBLICATIONS

MEASUREMENT

REPORT/PUBLICATION/TOPIC	AUTHORS/INSTITUTION	SUBJECT/COMMENT
1. Sampling and Analysis of Trace Organic Constituents in Ambient and and Workplace Air at Coal Conversion Facilities	R. D. Flotard, Argonne National Lab - July 1980	Air sample collecting for particulate and organic pollutants.
2. Theoretical Evaluation of Thermal Imaging for Detection of Erosive Wear of Internal Refractory-Lined Transfer Lines	C. K. Hsieh, W. A. Ellingson and K.C.Su	Modeling of temperature profiles resulting from refractory failure/cavities, etc.
3. The Proceedings of the 1980 Symposium on Instrumentation and Control for Fossil Energy Processes	Argonne Natonal Lab - June 1980	Collection of 58 papers.
4. Data Base for the Analysis of Compositional Characteristics of Coal Seams and Macerals	DOE/PC/30013-1, Pennsylvania State University	
5. Sampling and Analysis of Hydrocarbons in Combustion Gases	Irving Johnson, et al. Argonne National Lab, 1980	
6. Development of Instrumental Methods of Analysis of Sulfur Compounds in Coal Process Streams	Joseph Jordan, Pennsylvania State University, DOE report FE-2710-11	Quarterly Progress Report

TABLE 7.1. RECENT PUBLICATIONS (continued)

EQUIPMENT AND MATERIALS

REPORT/PUBLICATION/TOPIC	AUTHORS/INSTITUTION	SUBJECT/COMMENT
1. Application of Advanced Materials and Fabrication Technology to Let-Down Valves for Coal Liquefaction Systems	Battelle, Columbus Laboratories, January, 1977	Survey of pilot plant problems and lab testing of 21 different materials.
2. Development of a Ceramic Tube Heat Exchanger with Relaxing Joint	Micheal E. Ward, et al. FE-2556-30, Solar Turbines International - June, 1980	
3. In-Service Performance Results for a 10-inch CVD-Tungsten Coated Lock-hopper Valve	John F. Gardner, METC, DOE/METC/SP-80/19	
4. Valve Technology Development at the Morgantown Energy Technology Center	J. F. Gardner, METC, November, 1979	
5. Development of High-Temperature Turbine Subsystem Technology to a Technical Readiness Status-Phase II	General Electric Company, June, 1980, DOE Report FE-1806-91	
6. Correlation of the High Temperature Corrosion Behavior of Structural Alloys in Coal Conversions Environments with the Components of the Alloys and of the Corrosive Environment	I. G. Wright, Battelle, Columbus Laboratories, February, 1980, BMI-2059	Final report on program to determine effects of gasifier atmosphere on high temperature corrosion behavior.
7. Wear Resistant Materials for Coal Conversion and Utilization	F. E. Block, et al. Albany Research Center/B of M, April, 1980, DOE/OR/20687-TI	
8. Materials for Coal Conversion and Use	Vinod K. Nanjia, The Engineering Societies Commission on Energy, Inc., FE-2468-71	Material related problems associated with an integrated coal gasifier-fuel cell system and a combines cycle power system.

TABLE 7.1. RECENT PUBLICATIONS (continued)

EQUIPMENT AND MATERIALS (cont'd)

REPORT/PUBLICATION/TOPIC	AUTHORS/INSTITUTION	SUBJECT/COMMENT
9. A Program to Discover Materials Suitable for Service under Hostile Conditions Obtained in Equipment for the Gasification of Coal and Other Solid Fuels	B. A. Humphreys, et al. Metals Properties Council, DOE Report FE-1784-60, July, 1980	Annual report of the seven-phase MPC program.
10. Sulfidation Resistant Alloy/ Cladding for Internal Components of Coal Conversion Equipment	S. J. Vonk & Roger A. Perkins Lockheed, DOE Report FE-2299-29	
11. Update of Lock Hopper Valve Development	J. E. Gardner, F. D. Frubium, METC, CEP, February, 1980	
12. Long Term Materials Test Program	General Electric Company March, 1980, DOE/ET/15457-8	Preliminary operations plan for testing (10,000+ hours) of materials for PFB gas exposure.
13. FRACTURE Mechanics and Surface Chemistry Studies of Steels for Coal Gasification Systems	R.P. Wei, G. W. Simmons, Lehigh University, May, 1980 IFSM-80-104	Study of crack growth rates in steels exposed to hydrogen, water, H_2S.
14. Survey of Industrial Coal Conversion Equipment Capabilities : Values	W. A. Bush, E. C. Slade, ORNL ORNL/TM-6071	
15. Alloy Evaluation for Fossil Fuel Process Plants	C. M. Woods, T. E. Scott, Ames Laboratories, USDOE, 15-4750	Study of thermal coefficient of expansion and thermal stability and fracture growth rates in steels.
16. Coal Feeder Development Program	Lockheed Missile and Space Company, Inc., DOE Report FE-1792-61	Studies of coal extrusion type feeders.

TABLE 7.1. RECENT PUBLICATIONS (continued)

PROCESS

REPORT/PUBLICATION/TOPIC	AUTHORS/INSTITUTION	SUBJECT/COMMENT
1. Feasibility of Utilizing a Rotating Fluidized Bed for the Removal of Sulfur from Hot Gases	C. H. Waide, H. P. Serry, Brookhaven National Laboratory, April, 1980	
2. Gas Generator Research and Development - Bi-Gas Process	BCR & Phillips Petroleum Co., DOE Report FE-1207-69	
3. Development of Alcohol-Based Synthetic Transportation Fuels from Coal Derived Synthetic Gases	Chem Systems Research and Development Group DOE/ET/14858-2	
4. Improved Techniques for Gasifying Coal	Robert Graff, Joseph Yuushalmi, Clean Fuels Institute, City College, NY	
5. Alkali Metal Vapor Removal from Pressurized Fluidized-Bed Combustor Flue Gas	Irvine Johnson, et al. Argonne National Lab ANL/CEN/FE-80-5	
6. Mathematical Model of the Hygas Pilot Plant Reactor	J. P. Meyer, et al. Oak Ridge National Laboratory November, 1980	
7. Design and Simulation of a Recirculating Bed Reactor for Coal Hydrogasification	Lawrence J. Gajlas, Thomas W. Bierl, Carnegie Mellon Institute of Research, March, 1980, FE-3031-5	
8. Advanced Development of a Short-Residence-Time Hydrogasifier	Rockwell International Corp. July, 1980, DOE Report FE-3125-21	
9. Indirect Liquefaction of Coal	International Research and Technology Corp., June, 1980 DOE/EV/10291-TI	

TABLE 7.1. RECENT PUBLICATIONS (continued)

PROCESS (cont'd)

REPORT/PUBLICATION/TOPIC	AUTHORS/INSTITUTION	SUBJECT/COMMENT
10. Phase Equilibria for Design of Coal Gasification Processes, Dew Points of Hot Gases Containing Condensible Tars	Jim Pransnity, University of California, May, 1980 DOE/ET/10603/TI	
11. Design of Selective H_2S Absorption	C. Onmerkesk, Shell Internationale Petroleum	
12. Methanation in Catalyst-Sprayed Tube Wall Reactors: A Review	H. W. Pennline, R. R. Schehl, W. P. Haynes, A. J. Forney, PETC, DOE/PETC/TR-8017	Discussion of tests of Nichel-Raney catalyst-coated tube for methanation.

TABLE 7.1. RECENT PUBLICATIONS (continued)

OTHER

REPORT/PUBLICATION/TOPIC	AUTHORS/INSTITUTION	SUBJECT/COMMENT
1. Exploratory Research on Mutagenic Activity of Coal Related Materials	D. Warshansky, R. Schoeny, University of Cincinnati, June, 1980	
2. Materials-Process-Product Analysis of Coal Process Technology	Amil K. Iayota, Dalip S. Soni Mark Marshman, International Research & Technology Corp., October, 1979, IRT-19600/3	
3. Preparation of a Coal Conservation Systems Technical Data Book	D. Warshansky, R. Schoeny, University of Cincinnati, June, 1980	
4. Coal Data - A Reference	Eugene R. Slatjck, USDOE, July, 1980	Reference document on coal production.
5. Coal Conversion - 1979 Technical Report	USDOE, DOE/FE-0010	Summary of DOE program.